FILE LOWS PAPERS

THE MANAGEMENT OF APOLLO

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INTRODUCTION

Ten years ago today, man had not yet flown in space. But ten years ago today, things were about to happen:

-- on April 12, 1961, Yuri Gagarin, a Russian, was the first man to fly in space;

-- on May 5, 1961, Alan Shepard was the first American to enter space; and

-- on May 25, 1961, the United States made a national commitment: to land men on the moon before the end of the decade.

The rest is history. In July 1969, this commitment was met, when Neil Armstrong and Buzz Aldrin left a message on the moon: "Here men from earth first set foot upon the moon. ~~They~~ We came in peace for all mankind."

Even in retrospect, the job that had to be done still appears to be enormous. Government and industry teams were organized. Spacecraft and launch vehicles were designed, tested, built, and flown. Huge facilities for development, test, and launch came into being. At one time, 300,000 people in 20,000 industrial firms were involved -- of course, the majority of them were in fewer than 100 major firms.

The spacecraft alone, the Columbia and the Eagle, were made of 17 tons of aluminum, steel, titanium, copper, and synthetic materials. To this were added 33 tons of propellant. They had nearly four million parts, 230,000 feet of wire, more than 100,000 drawings, 26 major subsystems, 678 switches, and 410 circuit breakers, all fashioned into two flying machines that had to function with perfection to perform their assigned tasks. And on the launch pad, these spacecraft were on top of the giant Saturn V, more than 300 feet tall, weighing six million pounds, gulping 5.6 million pounds of propellant through its three stages and 11 engines.

The cost was also a staggering sum -- $20 billion. But this was at the low end of the cost range that was estimated when the job was started. And so, Apollo met all of its objectives. We landed on the moon, on time, and within the predicted costs.

My purpose this evening is to tell the story of Apollo from the management point of view. To do this, I will:

-- state why the decision to go to the moon was made;

-- discuss who was involved in doing the job;

-- describe how the job was done; and

-- cover special subjects, such as:

- the levels of decision making,
- NASA/industry relations,
- the importance of periodic reviews, and
- the importance of attention to detail.

For my conclusions, I will attempt to generalize some of the salient features of Apollo management, to summarize those features that may well be applied to other tasks that lie before us.

WHY

THE DECISION TO GO TO THE MOON

-- Decision made on May 25, 1961

-- String of Soviet firsts: Sputnik, Laika, Gagarin

-- Produced by Soviet system

-- Believed technological achievement implied military security

-- Challenged publicly, dramatically, successfully

-- space measure - visible - of state of technology

-- Unthinkable not to compete

-- Only question:

- how to compete
- to develop capability
- to succeed
- to demonstrate leadership

-- Answer:

- manned lunar landing
- hard to achieve
- far beyond existing capability
- good probability of leapfrogging

-- Most important:

- simply stated goal
- simply stated timetable

-- Equally important:

- decision announced by President
- approved by Congress
- with full knowledge of ultimate costs

-- Important also:

- announced to world
- world would watch each step as we progressed

WHO WAS INVOLVED IN APOLLO?

-- No special organization or legislation for Apollo!

-- In government -- NASA

-- NASA established, 1958, act of Congress

- to explore space for civilian purposes
- only other contender -- DOD -- ruled out

-- NASA nucleus -- NACA -- 8000 technical people, $100 million budget

-- By 1961 -- $1 billion budget, 17,000 people

-- managed some sizable projects

-- NASA's role -- that of technical management

-- Bulk of work carried out by industry under NASA supervision

booster
A/C
mission mode
facilities

-- The role of NASA:

- To formulate overall design of mission and hardware

- To decide on industry responsibility for different hardware elements

  -- e.g., stages

     engines

     spacecraft modules

     guidance systems, etc.

INHOUSE CAPABILI

- To select industrial firms to do each job

- To provide overall specifications for each hardware element

- To provide detailed interface specifications

- To supervise/monitor hardware contractors

- To conduct an in-house test program

This is where NASA's technical inhouse capabilit came in
- in test
- in decisions

- To plan and conduct the flight operations

- To select and train the astronauts

-- The role of industry:

- To design each element of hardware

- To make or buy subelements

- To supervise the subsystems development

- To manufacture or assemble the end product

- To test it – in industry or govt facilities
- To deliver it
- To assist in launch and flight operations

-- Authority and responsibility rested with NASA

-- Most of work, people, money, in industry

- Industry -- 300,000 people
- NASA -- 15,000, or 5% ON APOLLO AT PEAK

-- NASA organization:

- HQ Program Office
- Three Field Centers
  -- MSC role
  -- MSFC role
  -- KSC role

INHOUSE CAPABILITY

-- No special industrial organization

- individual firms did individual jobs

HOW WAS THE JOB DONE?

-- Will address hardware development, flight missions, and crew training

-- Hardware development

- Four significant aspects:
  -- design

-- test

-- understanding of failures

-- change control

- Design

-- combination of aircraft and missile practice and technology

-- build it simple, then double up on many components

-- examples

- ablative thrust chambers

- hypergolic propellants

- three fuel cells

- series/parallel redundancy

-- most important: minimize functional interfaces between major hardware elements

-- this simplifies organizational interfaces

-- Apollo example

- 100 wires between spacecraft and booster (one man)

- no functional wires between LM and CSM -- mechanical interface only

-- the role of man:

- avoid tedious repetitive tasks

- let man select data sources, switch between redundancies, back up automatic systems
- rendezvous/docking example

- Test

-- the single most important factor leading to Apollo success

-- every piece, part, component, subsystem, system -- had to pass prescribed tests

-- here is where government/industry team really had to work as a team

-- government and industry agreed on test conditions -- vibrations, temperature, stress, etc. vacuum

-- industry performed tests -- in their own facilities, or in government facilities

-- government approved results

-- government and industry worked together to resolve failures or problems -- EXAMPLE { VALVE PRIOR TO APOLLO 10 during drop test

- Understanding of Failures

-- many failures during test -- even during flight OR IN OTHER PROGRAMS

-- they could have been major, nearly catastrophic -- like Apollo 13

-- or minor, like toggle switch before Apollo 8

-- one cardinal rule -- all failures must be understood, and resolved before the next flight

-- go through toggle switch example

-- requires:

- good test specifications

- complete and open flow of information

- ability to react quickly when required

-- failure tracking system

- Control of Changes

-- system designed and tested

- important not to change it — change may invalidate previous test, flight, etc

- important to know in detail implication of every change

-- Changes are required to react to test failures, flight mission requirements, more detailed look at design

-- thus, it becomes of absolute importance to understand and control changes

-- describe Configuration Control Board — All decisions

- met 90 times June 1967 to July 1969

- considered 1,697 changes, approved 1,341, rejected 356

-- considered changes as large as hatch, as small as ballpoint pen

-- levels of change control delegated, to be discussed later

-- CCB my major management tool

- everyone, NASA and industry could propose changes for safety, efficiency, improvement, etc.

- requirements, cost and schedule discussed by all present -- NASA and industry

- decision mine, but immediate and in front of all people

- <u>Summary on Hardware Development</u>

-- simple design, easy interfaces

-- enormous test program

-- understand all failures

-- control all changes

- no magic mgt system -
- no special system

-- <u>Flight Missions</u>

- So far, talked only about hardware

- Management of flight operations, an equally important aspect of Apollo

- Sequence of missions

-- the task - build up to lunar landing with minimum number of flights

- proceed in stepwise fashion
- add reasonable increments

} do not stretch people or equipment beyond ability to absorb next step -

-- what is best series of missions to get to the moon in shortest period of time — too small a step: waste w/o significant gain; too large excessive risk -- people could not learn & practice

-- Apollo 7, 8, 9, 10, 11

- Mission techniques

-- mission planning: fit maximum number of tests (e.g., different rendezvous or guidance tests) into mission

-- data priority -- examples (LM guidance system -- no seat of the pants)

- given two or three data sources -- which one should be used
- what are limits, etc.

- Flight simulation

-- work out step-by-step procedure

- normal and emergency

-- a game of "what if's" -- what if engine does not light .. what if one fuel cell fails .. two?

-- rules for every situation

- rendezvous radar failure before separation
- rendezvous radar failure after separation

-- this preparation and practice, in a large measure, responsible for success of flights to date

-- Apollo 11 computer alarm example

-- Apollo 13 safe return

-- Apollo 14 computer procedure

- Flight crew preparation

-- another equally important management job -- will not cover here because of time

-- but mention configuration control for software, mission rules, crew procedures, etc. and why!

WHO MADE THE DECISIONS

-- In answering that question, we must take a look at basic organization involving:

- The President
- The Congress
- The Administrator of NASA
- The Apollo Program Office at HQ
- The NASA field centers — eg CCB again
- The prime and subcontractors

-- President -- only one decision: to go to moon

-- Congress -- no decisions, but annual approval of budget

-- NASA Administrator

- Contractor selection

- Review and approval of a few of most important decisions

  -- LOR

  -- Apollo 8

-- HQ Program Office

- Basic weight and performance

- Flight missions (e.g., F mission, Apollo 10)

- Flight schedule

-- Field Center Program Office

- Hardware performance and configurations

- Hardware changes

- Contractor management (prime)

- Mission planning and execution

-- Industrial Contractors

- Subcontractor selection

- Detailed design

- Manufacturing plan and processes

-- These were formal <u>decision</u> levels:

- They were generally changes to existing documents

- Only the man signing the document could change it

- e.g. -- HQ flight mission assignments document

-- There was also a continuing, open, informal exchange of information

- All (HQ and contractors) invited to my meetings
- When it came time for decision, the rationale for decision was already known to all.

NASA-INDUSTRY RELATIONS

-- How, then, did NASA and industry join to do this job

- Formally -- through the contract
  -- and through contract changes
- Informally -- through meetings to help each other do the best technical job.

-- It was this informal openness and trust that made the job go -- EXAMPLE (my two weeks in Downey?)

-- Periodically, more formal reviews were held:

- Design reviews
- Test reviews
- Acceptance reviews
- Pre-flight reviews

(Describe spacecraft acceptance review.)

ATTENTION TO DETAIL

-- I hope one point has come through

- That no detail is too small to consider

- Talk about switch on Borman's flight

- Plastic in ballpoint pen

-- The knowledge that there is risk in manned flight

- That the risk is high

-- And, therefore, that all levels of management must be willing to roll up their sleeves and consider technical problems to the most minute level of detail.

-- If I were to define the one quality of a manager that is the most essential one, it is to <u>ask the right question at the right time</u>; and, of course, be qualified to understand the answer.

WATER GLYCOL COOLANT ON LM PRIOR TO APOLLO 11.

-- When I write my book, the title will be, "we didn't ask the right question."

- Every flight failure I have seen could have been avoided if the right question had been asked in the first place.

-- You might aske me: how do you make sure you ask the right question?

-- I cannot answer that. The ingredients are all of the things I have talked about:

- A simple design
- Simple interfaces
- A baseline and control of changes
- But above all, good people and a free flow of communications among them. — TECHNICAL MANAGERS

CONCLUSIONS

I have often asked myself: what are the lessons from Apollo? How can we apply these lessons elsewhere? How do you answer the question, "if we can go to the moon, why can't we . . ."?

First, let's be sure we understand that Apollo was a very special program.

-- Its goal was set by the President.

-- Its timetable was set by the President.

-- Both the goal and the timetable were simply stated.

Second, it was a program that required a high level of technology, and did not require the solution of any sociological problems. It was unique in this respect.

And third, it received the continuing support, without any ups and downs, from those that provided the funds.

In return, Apollo met all of its obligations to the Nation: the goal, the timetable, and the predicted costs.

I can generalize from Apollo only to a similar class of program. Specifically, I would like to limit my conclusion only to programs that require technological solutions, as opposed to those that require political, economic, or sociological solutions. But given that kind of a limitation, I would think that the most important elements become:

1. A clearly stated goal.

2. A timetable to go with that goal.

3. If possible, a completely open program, where the public can measure progress.

4. A clear understanding, at all levels of responsibilities and authorities.

5. Excellent people, with open communications in all directions.

6. And finally, a dedication and desire by all to meet the established goal.

These, I believe, are the lessons of Apollo.

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